Okada et al.

SPECIFICATION(JP62-58883)

1. Title of the Invention

DRIVING APPARATUS

2. Claims

1. A driving apparatus for driving an object to be driven being in contact therewith by means of a plurality of piezoelectric elements, comprising:

a driving end for driving said object to be driven being in contact therewith,

a piezoelectric element 1 which possesses a displacement component in the direction of +45° with respect to the normal at the contact point between said object to be driven and said driving end, and

a piezoelectric element 2 which possesses a displacement component in the direction of -45° with respect to the normal at the contact point between said object to be driven and said driving end portion, wherein one end of said each piezoelectric element is fixedly attached to a base for fixing said piezoelectric element, the other end of said each piezoelectric element is fixedly attached to a coupling element that has a system structure having a high rigidity in the respective displacement directions of said piezoelectric elements and a low rigidity in the direction at right angles to the respective

displacement directions, said each piezoelectric element is applied with a driving frequency corresponding to a resonant frequency that depends on the rigidity of said each piezoelectric element.

2. A driving apparatus as claimed in claim 1, wherein said piezoelectric elements are fixedly attached to said bases and said coupling element by means of an adhesive.

3. A driving apparatus as claimed in claim 1, wherein said piezoelectric elements are fixedly attached to said bases and said coupling element, and are compressed by means of elastic members, and said piezoelectric elements are applied with a driving frequency corresponding to a resonant frequency that depends on the rigidity of said piezoelectric elements and the rigidity of said elastic members.

3. Detailed Description of the Invention

[Field of Industrial Application]

The present invention relates to a driving apparatus for providing driving force to an object to be driven. More particularly, it relates to a driving apparatus for providing driving force to an object to be driven, which uses piezoelectric elements which perform the piezoelectric effect.

[Prior Art]

As for a driving apparatus, which drives an object to be driven using the inverse piezoelectric effect, i.e., a

distortion generated by piezoelectric elements applied with a voltage, for example, as disclosed in the German document "FEINGERATETECHNIK" 1983, page 470 -473, a driving apparatus is known, in which plate-like piezoelectric elements presenting a configuration with distortion in a specific direction are arranged so as to positioned at right angles to each other in order to synthesize a vibration displacement, and the driving end portion thereof which comes into contact with an object to be driven is made to shift in an elliptic movement so as to drive the object to be driven in a specific direction.

[Problem to be solved by the Invention]

In the above-mentioned driving apparatus, since plate-like piezoelectric elements are used, a vibration is generated due to the elastic deformation of the plate-like piezoelectric elements. As a result, there is raised such a problem as the proper elliptic vibration of the driving end portion thereof generated by the piezoelectric elements is affected resulting in a decrease of the driving performance.

It is an object of the present invention to provide a driving apparatus that provides a stable and large driving force.

[Means for Solving Problem]

It has become to achieve the above-mentioned object of the invention in a manner as described below. In a driving apparatus for driving an object to be driven, a pair of laminated type piezoelectric elements are disposed while the each of the

elements is inclined to come into contact each other. One end of the each piezoelectric element is fixedly attached to the base by means of an adhesive or an elastic member, whereas the other end thereof is fixedly attached to a flexible structure that combines the piezoelectric elements together. The piezoelectric elements are vibrated at a resonant frequency of the resonant system that depends on the rigidity of the piezoelectric elements and the mass of the piezoelectric elements and the flexible structure, or that depends on the rigidity of the piezoelectric elements, the flexible structure and the flexible members. Further, the resonant displacement of the resonant system is transmitted to the driving end portion at the front end of the flexible structure.

[Working]

According to the invention, since the piezoelectric elements are driven at a driving frequency corresponding to the resonant frequency, it is possible to provide a large driving force to an object to be driven that comes into contact with the driving end portion thereof.

[Embodiments]

Hereinafter, a description will be made as to an embodiment of the invention.

FIG. 1 shows an apparatus according to the first embodiment of the present invention. In the figure, reference numerals 1 and 2 denote laminated type piezoelectric elements

that are located in a configuration corssing at right angle to each other. Reference numeral 8 denotes a driving end portion made of a wear resistant material, and is adhered and fixed to the front end of a flexible structure 7. Reference numeral 9 denotes an object to be driven. Reference numeral 10 denotes a base having inclined surfaces 10A of ±45° with respect to the contact plane at the contact point between the object to be driven 9 and the driving end portion 8. Said piezoelectric elements 1 and 2 are disposed on the inclined surfaces 10A respectively so that the directions of their vibrations are parallel with the directions of the normals of the inclined surfaces 10A. One end of each piezoelectric element is fixedly attached to the inclined surface 10A of the base 10, whereas the other end thereof is fixedly attached to the flexible structure 7. The directions of the mechanical displacement of the piezoelectric elements 1 and 2 are represented by arrows 5 and 6 respectively. That is to say, the piezoelectric elements 1 and 2 are sandwiched and fixedly attached between the base 10 and the flexible structure 7 so that the directions of vibrations of the piezoelectric elements 1 and 2 cross at right angles to each other, and to form an angle of ±45° , respectively, with respect to the contact plane. The flexible structure 7 includes a portion 7a facing the piezoelectric element 1 and a portion 7b facing the piezoelectric element 2. The portion 7a of the flexible structure 7 is rigid in the direction of the

arrow 5 and is flexible in the direction at right angles to the direction of the arrow 5. The portion 7a is symmetrical with the portion 7b and has a parallel link structure using an elastic hinge. Similarly, the portion 7b of the flexible structure 7 is rigid in the direction of the arrow 6 and is flexible in the direction at right angles to the direction of the arrow 6. The portion 7b is symmetrical with the portion 7a and has a parallel link structure using an elastic hinge. Accordingly, the displacement of the piezoelectric element 1 displaces the driving end portion 8 in the direction of the arrow 5 without being interfered by the piezoelectric element 2. Contrary, the displacement of the piezoelectric element 2 displaces the driving end portion 8 in the direction of the arrow 6 without being interfered by the piezoelectric element 1.

Basic operation of the above-mentioned apparatus according to the first embodiment of the invention is as described below. When the piezoelectric element 1 is applied with an AC voltage, the piezoelectric element 1 vibrates and is displaced in the direction of the arrow 5, and the driving end portion 8 is vibrated and displaced in the direction of the arrow 5 via the flexible structure 7, further receiving vibration and displacement of the driving end portion 8, the object to be driven 9 is driven in a specific direction. Herein, when the piezoelectric element 1 is changed to the piezoelectric element 2, to which an AC voltage is applied, since the piezoelectric

element 2 vibrates in the direction of the arrow 6, and the driving end portion 8 is vibrated and displaced in the direction of the arrow 6 via the flexible structure 7. Consequently, the driven direction of the object to be driven 9 is reversed.

To describe the above more in detail, when the piezoelectric element 1 is made to vibrate, the vibration displacement of the driving end portion 8 presents the frequency characteristics that depend on the rigidity of the piezoelectric element 1 and the flexible structure 7 and the effective mass of the piezoelectric element 1, the flexible structure 7 and the driving end portion 8. Herein, the rigidity of the portion 7a of the flexible structure 7 with respect to the displacement direction of the piezoelectric element 1 is large, and the rigidity of the portion 7b thereof is small. Accordingly, the vibration displacement of the drive end portion 8 is expressed as the vibration displacement of the front end of a spring when a spring system having an effective mass at the front end thereof as shown in FIG. 2, and which presents a spring constant that depends on the rigidity of the piezoelectric element 1, is applied with external vibration equivalent to the vibration displacement of the piezoelectric element 1. The spring system presents the frequency characteristics that have the resonant point that is expressed as, as shown in FIG. 3,

$$\text{frequency } f = (k/m)^{2/1} / 2\pi$$

wherein, m is the effective mass; k is the spring constant.

Accordingly, by adjusting the frequency of the AC voltage to be applied to the piezoelectric elements at a point adjacent to the above-mentioned resonant point, it is made possible to magnify the minute displacement and transmit it to the driving end portion by means of a small and simple structure resulting in an increase of the driving efficiency.

FIG. 4 (3) shows an apparatus according to the second embodiment of the invention. In the figure, the items having the identical reference numerals used in FIG.1 are the identical items as those shown in FIG. 1. Reference numeral 1′ and 2′ denote laminated type piezoelectric elements, which are configured in a rectangular shape, and each of them has a hole passing through at the center thereof. The piezoelectric elements 1′ and 2′ are different from the above described first embodiment in the following point. That is to say, the piezoelectric elements 1′ is fixedly attached to the inclined surface 10A of the base 10 and the flexible structure 7 via an elastic member 3 inserted through the hole, and the piezoelectric elements 2′ is fixedly attached to the inclined surface 10A of the base 10 and the flexible structure 7 via an elastic member 4 inserted into the hole.

The basic operation of the above-mentioned second embodiment of the invention is the same as that of the first embodiment of the invention. However, they are different from each other in a point where the rigidity and mass of the elastic

members 3 and 4 are added to the resonant spring system. That is to say, as shown in FIG. 5, in the second embodiment, the spring having the spring constant which depends on the rigidity of the piezoelectric elements 1′ and 2′ is disposed and coupled in parallel with the spring having the spring constant that depends on the rigidity of the elastic members 3 and 4 inserted into the piezoelectric elements 1′ and 2′. The vibration displacement of the driving end portion 8 portion is expressed as the vibration displacement of the front end of the springs when an external vibration equivalent to the vibration displacement of the piezoelectric elements is applied to the parallel spring system that has the effective mass of the piezoelectric elements, the flexible structure, the driving end portion and the elastic members at the front end thereof. Herein, defining that m_M represents the effective mass of the newly added elastic members, and k_M represents the constant which depends on the rigidity of the elastic members, the resonant frequency of the spring system is, as shown in FIG. 6, expressed as $f' = \{(k + k_M) / (m + m_M)^{1/2} / 2\pi\}$.

In the structure described in the second embodiment, since the rigidity of the elastic members 3 and 4 and the rigidity of the piezoelectric elements 1′ and 2′ are combined, such effect is rendered that the strength of the piezoelectric elements is increased. Furthermore, in this structure, since the piezoelectric elements 1′ and 2′ are compressed by the elastic

members 3 and 4 and are fixedly attached to the base 10 and the flexible structure 7, the piezoelectric elements are given with compressive force beforehand. Consequently, there is no danger that the piezoelectric elements are destroyed by the tensile stress.

As for a specific embodiment of the elastic members 3 and 4, bolts and springs may be used.

[Effects of the Invention]

As described above, according to the invention, it has become possible that minute vibration of the piezoelectric elements is magnified and transmitted to the driving end portion thereof, and a stable and large driving force is obtained.

4. Brief Description of the Drawings

FIG. 1 is an elevational view of an apparatus according to a first embodiment of the present invention;

FIG. 2 is an illustration representing the apparatus according to the first embodiment of the invention shown in FIG. 1 as a spring system;

FIG. 3 is a graph representing the characteristics of the spring system in FIG.2;

FIG. 4 is an elevational view in partial section of an apparatus according to the second embodiment of the present invention;

FIG. 5 is an illustration representing the apparatus according to the second embodiment of the invention shown in

FIG. 4 as a spring system; and

FIG. 6 is a graph representing the characteristics of the spring system in FIG. 5.

1, 2, 1", 2"	piezoelectric element
3,4	elastic member
5,6	displacement direction of the piezoelectric element
7	flexible structure
8	driving end portion
9	object to be driven
10	base
11	adhesive